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ABSTRACT

The causes of 19 world-wide changes in the earth's magnetic field, occurring between June and December 1967, were determined by examining magnetic field and plasma data for the solar wind near the earth. Seven of the events were classified as storm sudden commencements (ssc) and 4 as sudden impulses (si) by most stations reporting them. All of the ssc's were caused by hydromagnetic shocks. Two of the si's were negative impulses (si^-) and were caused by tangential discontinuities across which the density decreased. The other 2 si's were distinct pulses in the magnetograms, for which we suggest the designation pl^+, and were caused by dense spots in the solar wind with dimensions $\approx$ .005 AU. There was no consensus among the reporting magnetic observatories as to whether the remaining 8 events should be called si's or ssc's. Five of these events were caused by shocks and the other 3 by tangential discontinuities in the solar wind, but there seems to be no sure way to predict the type of structure from the shape of the magnetogram pulse. The rise time of the impulse in the H component in the magnetogram is apparently determined by something other than the type, the speed, or the thickness of an interplanetary discontinuity which caused the event.

THE CAUSES OF SUDDEN COMMENCEMENTS AND SUDDEN IMPULSES

I. INTRODUCTION

The introduction of the solar wind into the relationship between the sun and the earth means that it is possible for a geomagnetic ssc or si to be caused either by a propagating discontinuity or by a discontinuity convected past the magnetosphere with the bulk speed of the plasma.

Gold (1955) suggested that ssc's were caused by shock waves propagating through the interplanetary medium from the sun. Subsequently, Sonett et al. (1964) reported direct interplanetary observations of a shock-like discontinuity which was moving from the sun and was associated with a ssc that was observed by 51 ground stations. Other observations of propagating events thought to be shocks, for which both plasma and magnetic field information was available, have been described by Ogilvie and Burlaga (1969). Nishida (1964) suggested that ssc's could also be produced by a non-shock mode, presumably a hydromagnetic wave or a tangential discontinuity.

Nishida (1964) suggested that the non-shock mode discontinuity must be the cause of si. Sonett and Colburn (1965) proposed that the si^- is due to a reverse shock. Gosling et al. (1967) presented interplanetary observations which showed a discontinuous decrease in density and a gradual increase in temperature at the time of a world-wide, discontinuous decrease in the earth's field, thus establishing that an si^- could be caused by a non-shock mode discontinuity. Ogilvie et al. (1968a) examined simultaneous interplanetary plasma and magnetic field data associated with a similar si^- and observed a discontinuous decrease in density, and discontinuous increase in magnetic field intensity and no appreciable change in temperature, showing that the si^- was caused by a hydromagnetic discontinuity whose signature was that of a tangential discontinuity. Ogilvie et al. (1968a) have also shown that positive impulses si^+ are sometimes caused by hydromagnetic discontinuities. Gosling et al. (1967) reported an observation of a discontinuous decrease in temperature at the time of an ssc, showing that the event was not caused by a forward shock, but not ruling out a reverse shock.

It is clear from these observations that both si and ssc can be produced in a variety of ways. Taylor (1968) examined the causes of 36 ssc events using interplanetary magnetic field data from Explorer 28. He concluded that 8 of these events were due to tangential discontinuities, and that 26 were possible shocks which caused the "larger" ssc events. It is of interest to carry out a similar study using both interplanetary plasma and magnetic field data to see if it is possible to predict, using only ground observations, which type of interplanetary structure is responsible for a given si or ssc.

Nishida (1964) suggested that the rise time of the impulse is small ($\lesssim$2 min.) for the events caused by shocks and large ($\gtrsim$2 min.) for events caused by thicker, non-shock mode disturbances which propagate slowly or not at all, but this has not been confirmed with direct interplanetary observations.

A theory of the interaction of the solar wind with the earth shows that the change ΔH in the horizontal component of the earth's magnetic field should be proportional to the change in momentum flux. Siscoe et al. (1968), from a study of 13 si^+ events, showed that from this theory one can calculate the change in momentum flux using ΔH and an empirical constant of proportionality which possibly varies with time. Ogilvie et al. (1968a) showed a similar result for both si and ssc events. Clearly, ΔH alone is not sufficient to identify the type of discontinuity which causes the event.

This paper presents observations which identify the interplanetary hydromagnetic structures that caused 19 ssc's and si's during June-December, 1967. It also answers the following questions: 1) Given the classifications si or ssc for an event from several worldwide magnetic observatories, can one predict empirically the type of physical structure which caused the event? 2) Given the rise time for an event, can one estimate the thickness of the 'discontinuity' which caused the event?

II. INSTRUMENTS

The plasma and magnetic field data used for this study were obtained by Explorer 34, a satellite whose orbit had an apogee of $34R_e$.

The plasma data were obtained with an instrument described by Ogilvie et al., (1968a). An electrostatic analyzer and a velocity selector are used to give proton and alpha particle spectra separately. The proton differential energy spectrum consists of 14 channels in the range 310 eV - 5100 eV., which form a geometric progression with a ratio 1.24:1 and have a full width $\Delta E/E \gtrsim 5\%$. Since energy spectra are formed by counting for 2.56 sec. at each energy level, during which time the satellite revolves once about an axis perpendicular to the ecliptic plane, a typical 3-bar spectrum is obtained in 7.8 sec; successive proton spectra are obtained at 3 minute intervals.

The plasma distribution function f (v) for a given proton spectrum is represented by fitting the unfolded spectrum by a series of maxwellian arcs, as described by Burlaga and Ogilvie (1968) and Ogilvie et al., (1967). The fluid parameters — density n, mean speed u, and temperature T — are obtained by taking moments of f (v):

$$n = \int f(v)\, dv$$

$$u = \frac{1}{n} \int v\, f(v)\, dv$$

$$T = \frac{m}{nk} \left[\int v^2\, f(v)\, dv - nu^2 \right]$$

The magnetic field data were obtained by Ness and Fairfield with a triaxial, flux-gate magnetometer (see Fairfield, 1969). The digitization error is $\pm .16\gamma$ and the components of the magnetic field are measured to an accuracy $\approx \pm .2\gamma$. Complete vector measurements of the magnetic field are determined at 2.56 sec. intervals. The magnetic field observations are used here in the form of averages over 20.45 sec., computed from eight successive measurements of each component of the magnetic field.

III. SELECTION OF SSC AND SI EVENTS

We consider events which, according to tabulations in Solar-Geophysical Data, were classified as ssc (or si) by 10 or more magnetic observatories and which occurred in the interval June-December, 1967. This interval was chosen because it is the period when nearly continuous measurements of the solar wind were made by Explorer 34. The number of observatories required, ≥ 10, was chosen to insure that the event was seen worldwide and was thus likely to be a real physical effect caused by changes in the solar wind. Eight of the events occurred when Explorer 34 was not in the interplanetary medium, i.e. inside the earth's bow shock; these will not be considered further. There were two events for which the quality of the interplanetary data was poor; these events are also not considered further. This leaves 19 ssc-si events, shown in Table I, for which high-quality interplanetary measurements are available. These events form the basis for this study.

The first column of Table I shows the number of the issue of Solar-Geophysical Data from which data for the events were obtained. The column labelled #(si) gives the number of stations which classified an event as (si) and the column #(ssc) gives the number of stations which classified that event as an ssc. The next column gives the total number of stations that reported the event.

Table I shows that an event is seldom called an ssc (or si) by all of the stations which report it. This is because the designations ssc and si are basically subjective. (For definitions, see Provisional Atlas of Rapid Variations.) Of course, these designations are meaningful if and only if nearly all stations can agree on which of the two is appropriate for a given event. Let us define a parameter A,

$$A \equiv \frac{\#(ssc) - \#(si)}{\#(ssc) + \#(si)}$$

if all stations call an event an ssc, then $A = 1$, and if all stations call an event an si, then $A = -1$. The basic difference between $A = 1$ and $A = -1$ events is that the former are followed by storms while the latter are not. Values of A are shown in Table I for the events for which Explorer 34 interplanetary observations are available. The distribution of the number of events as a function of A is shown in Figure 1. This distribution is bi-modal, but it is clear that there are several events which cannot be unambiguously denoted as si or ssc, and that distinct si's were reported less frequently than ssc's. The increased width of the distribution for A negative over that for A positive may be due to the fact that positive A events, being followed by magnetic storms, stand out in the records more than small sudden impulses.

IV. INTERPLANETARY STRUCTURES CAUSING THE GEOMAGNETIC EVENTS

This section considers the question "what caused the events listed in Table I"? It will be shown that all of the events in Table I were associated with abrupt changes in the state of the solar wind near the earth, some representing shocks propagating past the earth, others representing tangential discontinuities convected past the earth, and two representing new kinds of structures.

It has already been established by Ogilvie, Burlaga and Wilkerson (1968a) and by Ogilvie and Burlaga (1969) that 8 of the events in Table I were caused by hydromagnetic shocks; these events are indicated by the asterisks in Table I. Thus, we need only consider the causes of the remaining 11 events in Table I. Interplanetary plasma and magnetic field data from Explorer 34 are shown for these events in Figure 2a, b, c, d.

Four of the events in Figure 2 (June 30, Aug. 4, and the two on Dec. 16) are clearly not shocks. The anticorrelation between density and magnetic field intensity, and the negligible change in bulk speed and temperature for these events suggests that they are tangential discontinuities such as Burlaga (1968) has discussed. One of the events in Figure 2 (Aug. 29) has been identified as a shock by Ogilvie and Burlaga (1969), and is included here only to show that it was a very weak shock, which may explain why it was not identified as an ssc ($A = -.19$). The remaining events in Figure 2 require a more detailed discussion.

July 25.

The magnetic field intensity increased $\simeq 5.0\gamma$ within 20 sec. and the direction did not change appreciably, as is characteristic of shocks. The plasma quantities, based on 2-bar and 3-bar spectra, show a small increase in n and u (n goes from $\approx 3.5 cm^{-3}$ to $\approx 4.4 cm^{-3}$, and u goes from 413 km/sec to 439 km/sec). The temperature does not show a significant change, but fluctuates considerably in the interval shown, ranging from 4.0×10^4 °K to 1.2×10^5 °K, so a real change may be obscured by the fluctuations. Thus, although the signature is somewhat ambiguous, the structure is probably a shock.

August 11.

Figure 2b shows a slow rise in density which is followed several minutes later by a rapid decrease to the original density. If we think of this structure as a pulse instead of two discontinuities, it indicates the presence in the solar wind of small regions ($\approx .005$ AU) in which the density is appreciably higher than in the ambient plasma. The passage of this region past the earth produced an impulse in the earth's magnetic field. Figure 3 shows that the shape of the impulse in the magnetogram reflects the shape of the density-time curve in Figure 2b. Thus, the existence of the density pulse could have been inferred from the magnetograms.

September 20.

This event was very complicated, and very pronounced in the magnetograms (see Figure 3). The interplanetary data were similarly complex. Figure 4 shows the horizontal and vertical components of the earth's magnetic field, together with interplanetary plasma and magnetic field data, for 5 hours about the time of the event. The data are shown with higher resolution in Figure 2b. Note the density pulse, somewhat similar to that on August 11. The leading edge of the pulse appears to be a tangential discontinuity across which the density increases and the magnetic field intensity and temperature decrease. This is followed a few minutes later by a large, abrupt increase in the magnetic field intensity, density, temperature and bulk speed, but no appreciable change in the magnetic field direction. This discontinuity, though not clearly resolved by the plasma analyzer, appears to be a hydromagnetic shock, which is followed again by a large drop in density and a corresponding, discontinuous increase in B, probably indicating a tangential discontinuity. Several minutes later another large discontinuous density decrease occurs with a corresponding large increase in B (B goes off-scale in Figure 2b) which probably indicates another tangential discontinuity. There is a change in the earth's magnetic field corresponding to each of the discontinuities just described.

October 8.

From Figure 2c, we see that the Oct. 8 event was caused by a structure which resembles a diffuse tangential discontinuity. A nearly discontinuous increase in B is associated with a drop in density from $23 cm^{-3}$ to $10 cm^{-3}$ in a 10 minute interval. The temperature appears to decrease at the time of the "discontinuity", but this could be an instrumental effect connected with the decrease in density. The structure is clearly not a shock, but it does resemble a tangential discontinuity.

October 28.

Plasma data are based on 3 and 4 bar spectra. There is a small but real increase in the bulk speed and temperature, a large, shock-like increase in B and a clear directional discontinuity, but no noticeable increase in density. A large increase was observed in the horizontal component of the earth's field, (see Figure 3 and Table II) which according to Siscoe et al. (1968) implies an increase in the momentum flux, nu^2. The observed change in u, which is known within 2%, is not large enough to account for the change in momentum flux so the ground data imply an increase in density. It is possible that the density did increase but was not measured because the wind was deflected away from the ecliptic plane so that a fraction of the particles did not enter the 18° aperature of the instrument. We conclude that the structure was probably a shock.

November 3.

Three bar spectra were observed before the discontinuity, and 2 and 3 bar spectra were observed afterward. There was clearly an increase in B, n and u across the discontinuity but the temperature change is not clear. We cannot identify the structure unambiguously, but it appears to be a shock.

December 29.

The satellite was in the sheath just before the event occurred, and entered the solar wind at the time of the event. The emergence into the solar wind suggests that a discontinuous increase in density drove the bow shock inward past the satellite. Ordinarily, B and T are larger in the sheath than in the solar wind, but Figure 2d shows that the opposite was true for this event. Thus, it appears that n, T and B increased across the discontinuity, suggesting that the event was caused by a shock.

In summary, 8 of the 19 events in Table I were caused by shocks which have been discussed in previous papers, 5 were associated with interplanetary discontinuities with signatures suggesting that they were tangential discontinuities, 4 were associated with interplanetary discontinuities with signatures suggesting that they were shocks, and 2 were caused by small, dense regions in the solar wind. The identifications are listed in Table I.

V. RELATION BETWEEN A AND THE TYPE OF INTERPLANETARY STRUCTURE WHICH CAUSED THE EVENT

We shall now combine and generalize the results of the preceding 2 sections to determine whether one can use the si-ssc designations for an event, to identify the type of interplanetary structure which caused the event. The si-ssc designations for an event may be summarized by 2 parameters: the total number of stations reporting the event and the parameter A for the event, defined in Section III.

Table I shows that the eight most prominent events (those reported by ≥ 32 stations) were all caused by hydromagnetic shocks. It is significant that not all of these events were classified as sudden commencements — for Aug. 29, A = -.19 and for Nov. 29, A = 0.1.

Let us define an event to be a sudden commencement if $A > .75$ for that event. Table I shows 7 sudden commencements and indicates that all were caused by shocks. Thus, a sudden commencement, defined by $A > .75$, indicates the arrival of a hydromagnetic shock.

Now consider the sudden impulses in Table I, defined by $A < -.75$. There are only 4 of these — at 1505 UT on Aug. 11, Sept. 20, Oct. 8 and the event at 1133 UT on Dec. 16. The Aug. 11 magnetogram shows a pulse, not a step-like increase, and the interplanetary observations in Figure 2b show this reflected in an increase in density followed by an equal decrease. Transforming to a frame moving with the solar wind, this implies a region with dimensions ≈ 0.005 AU in which the density was higher than the surrounding region. The Sept. 20 event, like the Aug. 11 event, was also seen in the magnetograms as a large pulse. This was again caused by a small region with enhanced density, but a more complicated one than that on Aug. 11, consisting of both a shock and a few tangential discontinuities. The 2 remaining events, Oct. 8 and Dec. 16, were negative sudden impulses and were caused by tangential discontinuities across which the density decreased.

Thus, sudden impulses, defined by $A < -.75$, were caused by interplanetary structures, but not of a single type. These results, although based on relatively few events, suggest that it would be useful to consider revising the si classification by dividing si events into three sets: 1). step-like increases of the H component of the earth's magnetic field which are not followed by a magnetic storm (si^+) 2). step-like decreases in the H component which are not followed by a magnetic storm (si^-) and 3). pulses, (pl^+) characterized by a sudden increase in the H component followed within minutes by a sudden decrease of the H component to the pre-pulse value.

Events in Table I with $-.75 < A < .75$ were not classified unambiguously as sudden impulses or sudden commencements. Five of these were caused by shocks, and three were caused by tangential discontinuities. Two of the three tangential discontinuities were associated with negative A and 3 of the 5 shocks were associated with positive A. There is thus a tendency for shocks to be identified as sudden commencements and tangential discontinuities as sudden impulses, but the relation is not good enough for predictions.

VI. RELATION OF RISE TIME TO TYPE OF DISCONTINUITY

Nishida (1964) suggested that ssc's can be divided into two classes, one with rise times $\lesssim 2$ min. which he attributed to shocks, and another with rise times $\gtrsim 2$ min. which he attributed to small amplitude waves or tangential discontinuities. The basis for this hypothesis is a statistical relation which he found between the rise time for an ssc and the speed V_R of the discontinuity or wave relative to the solar wind. This showed that rise times $\gtrsim 2$ min. were associated with speeds 50 km/sec. $\lesssim V_R \lesssim$ 500 km/sec. and rise times $\lesssim 2$ min. were associated with 700 km/sec. $\lesssim V_R \lesssim$ 1000 km/sec. This relation appears to rule out tangential discontinuities, since for these structures $V_R = 0$, but it must be remembered that due to the lack of direct velocity measurements, Nishida computed V_R from $V_R = \bar{V} - V_w$. Here $\bar{V}$ is the mean propagation speed, computed from the time between the flare and ssc; this is known to be higher than the local speed of the shocks at the earth (1 AU). He computed V_w from a modification of the relation between V_w and K_p which is known to give a poor correlation (Snyder et al. (1963), Ogilvie et al. (1968b). Thus, Nishida's quantitative results must not be interpreted literally, but the idea of linking the rise time of a geomagnetic disturbance with speed and type of the causative discontinuity is interesting and deserves further study.

Estimated rise times for all events, probably correct to 1 minute, are given in Table I. Figure 5 shows rapid-run magnetograms for the events illustrated in Figures 2a, 2b, 2c, 2d.

Consider first the ssc events, i.e. events for which $A \geq .75$. Table I shows that there are 7 such events and that all were caused by shocks. The rise times for these events can nevertheless be divided into two groups: 5,7,6,5,6 and 2,2, minutes. Thus, one cannot say that the ssc's with long rise times are due to tangential discontinuities while those with short rise times were caused by shocks.

Now consider the relation between the shock speed and the rise time for the ssc events. Shock speeds have been calculated by Ogilvie and Burlaga (1969) for 3 of the ssc events, June 26, Sept. 23 and Sept. 19. The speeds are 482 km/sec., 416 km/sec. and 497 km/sec., respectively, and the corresponding rise times are 6 minutes, 2 minutes and 2 minutes, respectively. Although the 6 and 2 minute rise times represent almost the extreme values observed, there is very little variation in observed velocity and the lowest speed not corresponding to the longest rise time.

It has been noted that not all shocks produce events with short rise times ($\lesssim$2 min.). Table I shows that not all tangential discontinuities produce impulses with large rise times; for example, the June 30 and Oct. 8 events were produced by tangential discontinuities but the t's were low — 2 min. and 3 min., respectively. Thus, t cannot be used to distinguish between the shock mode and non-shock mode for a particular event. Furthermore, t cannot be used even in a statistical sense to infer the type of discontinuity for the events in Table I, since the average t for the shocks in Table I was $\bar{t}_s = 4$ min., while that for the other events was 5 min., which is not significantly different from $\bar{t}_s$. It should be noted that t is also not correlated with A for the events in Table I.

Nishida (1964) suggested that the rise time of an ssc is proportional to the thickness of the discontinuity which caused the impulse. If this were the case for all kinds of impulses, one would expect an exceptionally large t for the si^- on Oct. 8, which was caused by a "discontinuity" whose thickness was $\gtrsim$ (6 min.) $\times$ (60 sec/min) $\times$ (400 km/sec) $= 1.4 \times 10^5$ km. In fact, however, the "rise time" (actually, the "fall time", since the event was a negative impulse) was only 3 minutes which is relatively small compared to the other t's in Table I. One expects that shocks would be thinner than tangential discontinuities, since tangential discontinuities can gradually broaden as a result of diffusion, but it was already noted that $\bar{t}_s$ for shocks was not appreciably smaller than t for tangential discontinuities. Thus, we conclude that t is <u>not</u> determined by the thickness of the interplanetary structures which caused the events in Table I.

VII. SUMMARY

In the interval June-December, 1967 there occurred 19 impulsive changes in the earth's magnetic field which were reported as ssc's (or si's) by 10 or more magnetic observatories, and for which corresponding interplanetary plasma and magnetic field data were available from Explorer 34.

There was only one of the 19 events for which all magnetic observatories agreed on the appropriate designation. In a few cases, $\approx 50\%$ of the observatories reported an event as an ssc while the remaining $\approx 50\%$ of the observatories reported the event as an si. Thus, the final designation of ssc or si must represent a kind of consensus among the observatories, and cannot always be assumed to be unique. In view of this ambiguity, we have defined a parameter, A, which measures the combined judgement of all the observatories for a given event. We call an event a storm sudden commencement if $A > .75$ and a sudden impulse if $A < -.75$. Seven of the 19 events were ssc's and 4 were si's in this sense. The remaining 8 events cannot unambiguously be classified as si or ssc.

An examination of the corresponding interplanetary plasma and magnetic field data showed that a distinct interplanetary structure was present near the earth within minutes of each magnetic impulse. It was found that <u>all</u> of the storm sudden commencements were caused by hydromagnetic shocks, but that not all shocks produced an impulse which was unanimously designated as an ssc by observing stations. It was found that 2 of the sudden impulses, the 2 step-like decreases in the H component, were caused by tangential discontinuities across which the density decreased. The other 2 sudden impulses, which were distinctly different from the step-like ssc's or si's were associated with small regions ($\approx .005$ AU) in which the density was appreciably higher than in the surrounding plasma. One of these was simply a dense spot, but the other was associated with a shock which was apparently driven by a narrow high-speed stream. In view of the distinctly different magnetogram traces and the corresponding different associated interplanetary structures, it is suggested that one should consider revising the si classification to distinguish between three types of magnetogram impulses: si^+, a step-like increase in the H-component of the earth's magnetic field which is not followed by a magnetic storm; si^-, a step-like decrease in the H-component which is not followed by a storm; and pl^+, a pulse-like change in the H-component characterized by a rapid increase in H followed moments later by a rapid decrease to the initial value of H. With this system, the present observations, which are admittedly limited, suggest that 1) an ssc ($A>.75$) implies a shock, 2) an si^- ($A<-.75$) usually implies a tangential discontinuity across which the density decreases, 3) a pl^+ implies a small dense region in the solar wind. No evidence for a reverse shock was found. Five of the events for which $-.75 < A < .75$ were caused by shocks and three were caused by tangential discontinuities. One cannot infer a shock or tangential discontinuity from A for these intermediate A events — some of the negative A events were caused by shocks and one positive A event was caused by a tangential discontinuity.

We considered the hypothesis that the rise time of a magnetogram impulse due to a tangential discontinuity is longer than that for an impulse due to a shock, and concluded that no such relationship exists for the events in this study. Shock speeds are available for three of the ssc events; we find no relation between the rise time and the shock speed. It is also shown that a relatively wide discontinuity can produce a relatively short rise time. Thus, the rise time is apparently determined by something other than the type, the speed, or the thickness of an interplanetary discontinuity.

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Table I

si's and ssc's Reported by 10 or More Stations, June-December 1967

Ref.	Month	Day	Time	# (si)	# (ssc)	# (si) + # (ssc)	A	t (min.)	Remarks
280	June	5	1912	2	44	46	.91	5	*shock
280		25	0222	1	54	55	.96	7	*shock
280		26	1459	8	35	43	.77	6	*shock
280		30	1817	12	3	15	-.60	2	T.D.
283	July	25	1739	15	9	24	-.25	2	shock
283	August	4	0702	7	15	22	.36	6	T.D.
283		11	0505	1	46	47	.96	5	*shock
283		11	1505	14	1	15	-.86	5	pulse
283		29	1738	13	19	32	-.19	3	*shock
283	Sept	13	0345	1	43	44	.95	2	*shock
283		19	1959	3	38	41	.85	2	*shock
283		20	1736	16	2	18	-.78	6	shock and T.D.'s (pulse)
285	Oct	8	1937	11	1	12	-.83	3	diffuse T.D.
285		28	1637	13	34	47	.45	3	shock
285	Nov	3	0914	0	18	18	1	6	shock
285		29	0512	18	22	40	.1	6	*shock
285	Dec	16	1025	14	4	18	-.56	6	T.D.
285		16	1133	19	1	20	-.9	5	T.D.
285		29	2227	4	11	15	.46	7	shock

*Identified as a hydromagnetic shock by Ogilvie and Burlaga (1969).

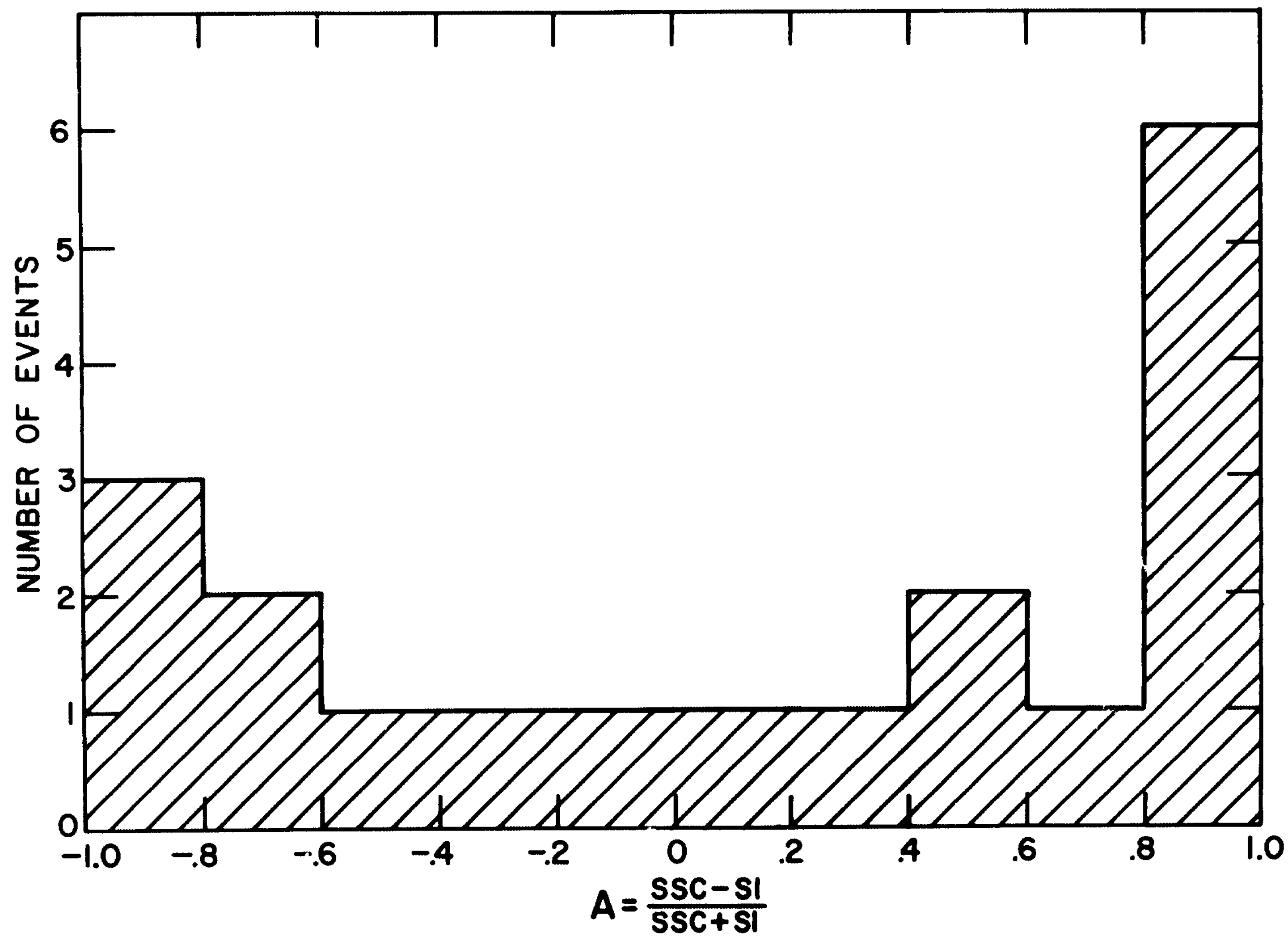

Figure 1. An abrupt change in the H component of the earth's magnetic field may be reported as an ssc or an si by a magnetic observatory. If all observatories reporting an event classify the event as ssc, then $A = 1$ for that event, and if all classify it as si, then $A = -1$ (see the text for the definition of A). This figure shows the distribution of the events in Table I as a function of A. One can see that there are basically two classes, ssc and si; but several events cannot be described as an si or an ssc because there was no consensus among the observatories as to which of these two designations is correct.

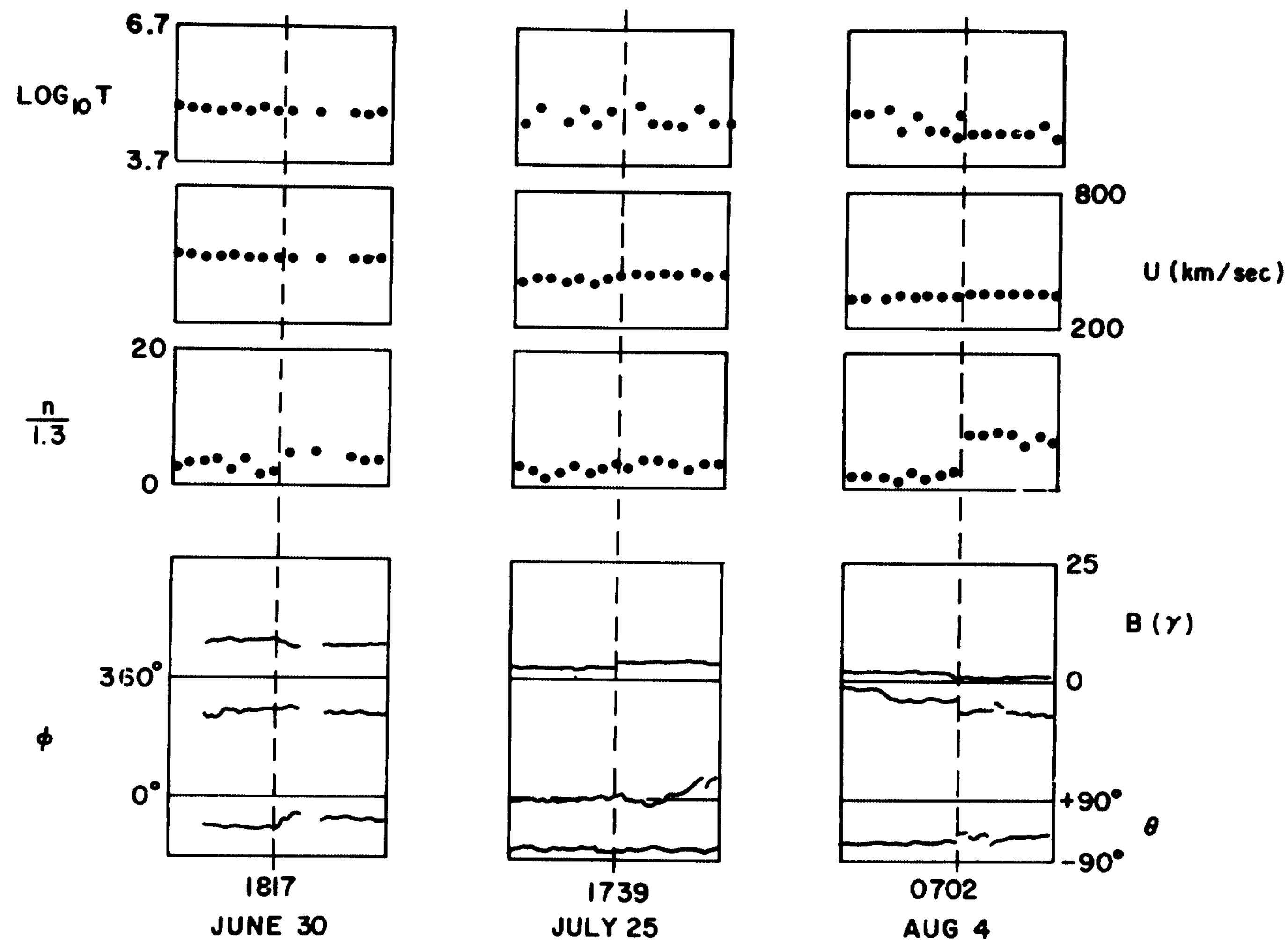

Figure 2a. Interplanetary plasma and magnetic field data for intervals near the times of 3 of the events in Table I. From top to bottom are the proton temperature, bulk speed and density, the magnetic field intensity, magnetic field longitude ϕ and latitude θ. These quantities are plotted versus time; the width of each box corresponds to 45 minutes. The plasma points are at 3 minute intervals. The magnetic field traces are from contiguous 20 sec. averages which are computed from averages of the measured magnetic field components.

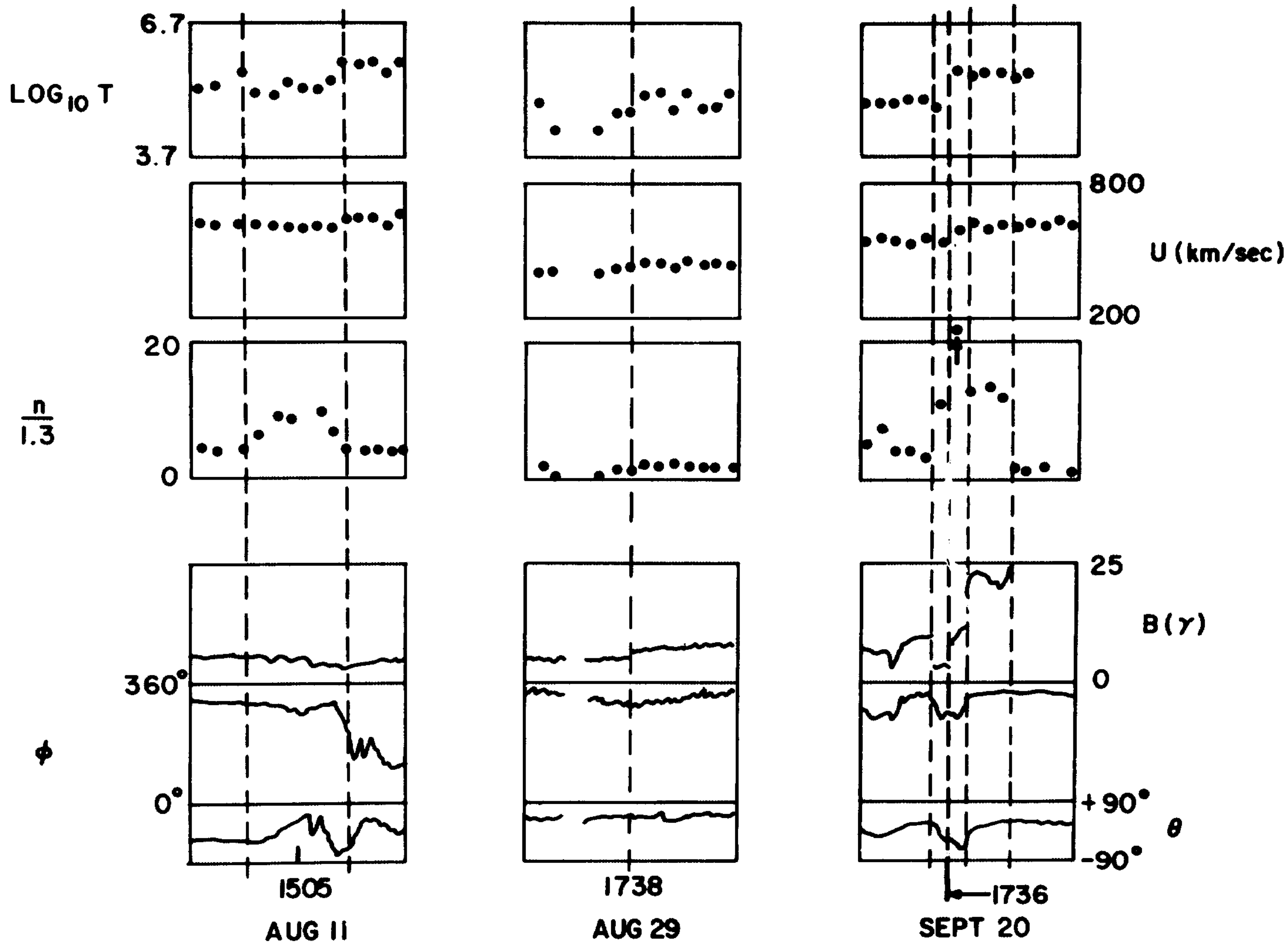

Figure 2b. Interplanetary plasma and magnetic field data for intervals near the times of 3 of the events in Table I. From top to bottom are the proton temperature, bulk speed and density, the magnetic field intensity, magnetic field longitude ϕ and latitude θ. These quantities are plotted versus time; the width of each box corresponds to 45 minutes. The plasma points are at 3 minute intervals. The magnetic field traces are from contiguous 20 sec. averages which are computed from averages of the measured magnetic field components.

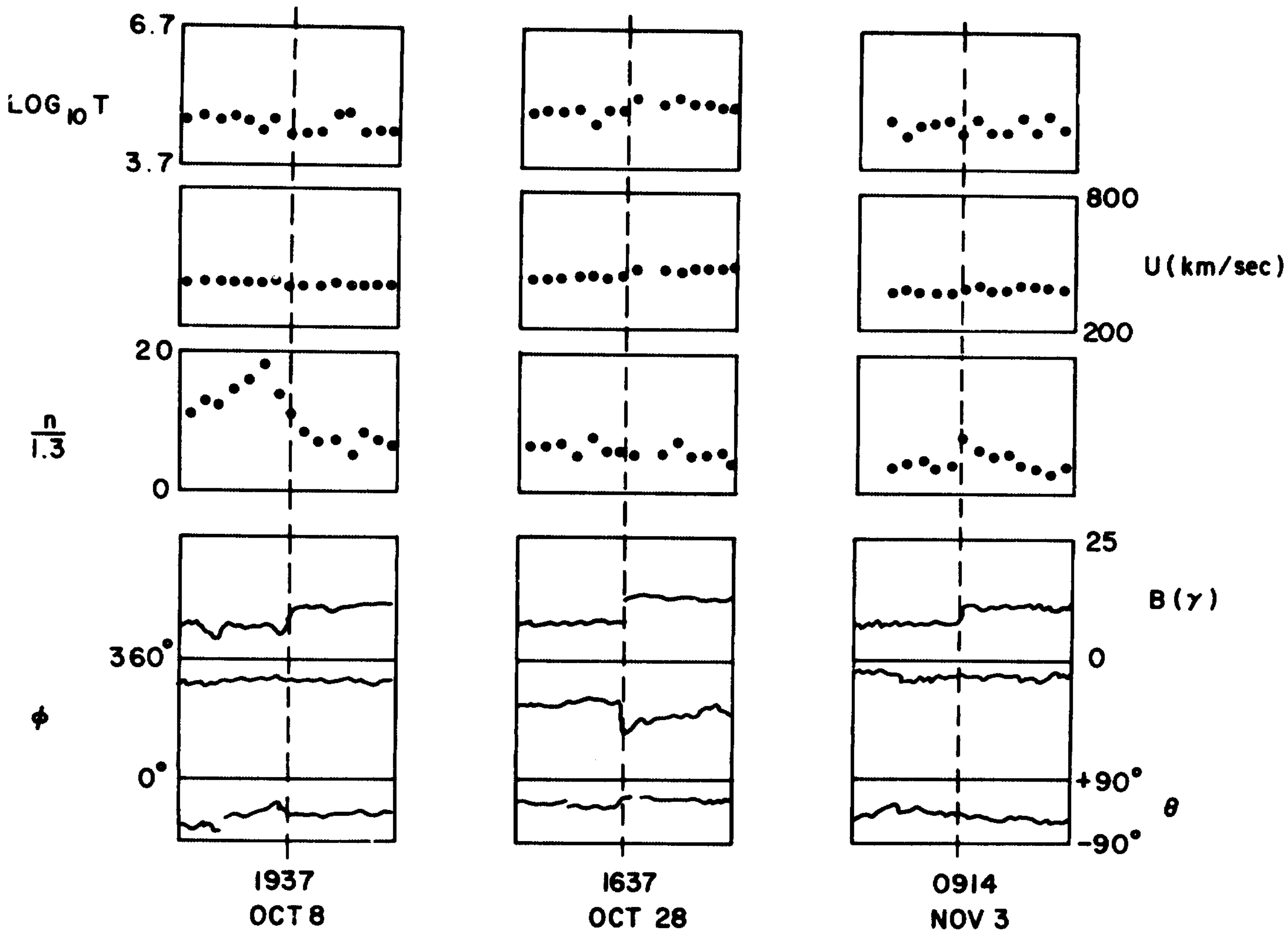

Figure 2c. Interplanetary plasma and magnetic field data for intervals near the times of 3 of the events in Table I. From top to bottom are the proton temperature, bulk speed and density, the magnetic field intensity, magnetic field longitude ϕ and latitude θ. These quantities are plotted versus time; the width of each box corresponds to 45 minutes. The plasma points are at 3 minute intervals. The magnetic field traces are from contiguous 20 sec. averages which are computed from averages of the measured magnetic field components.

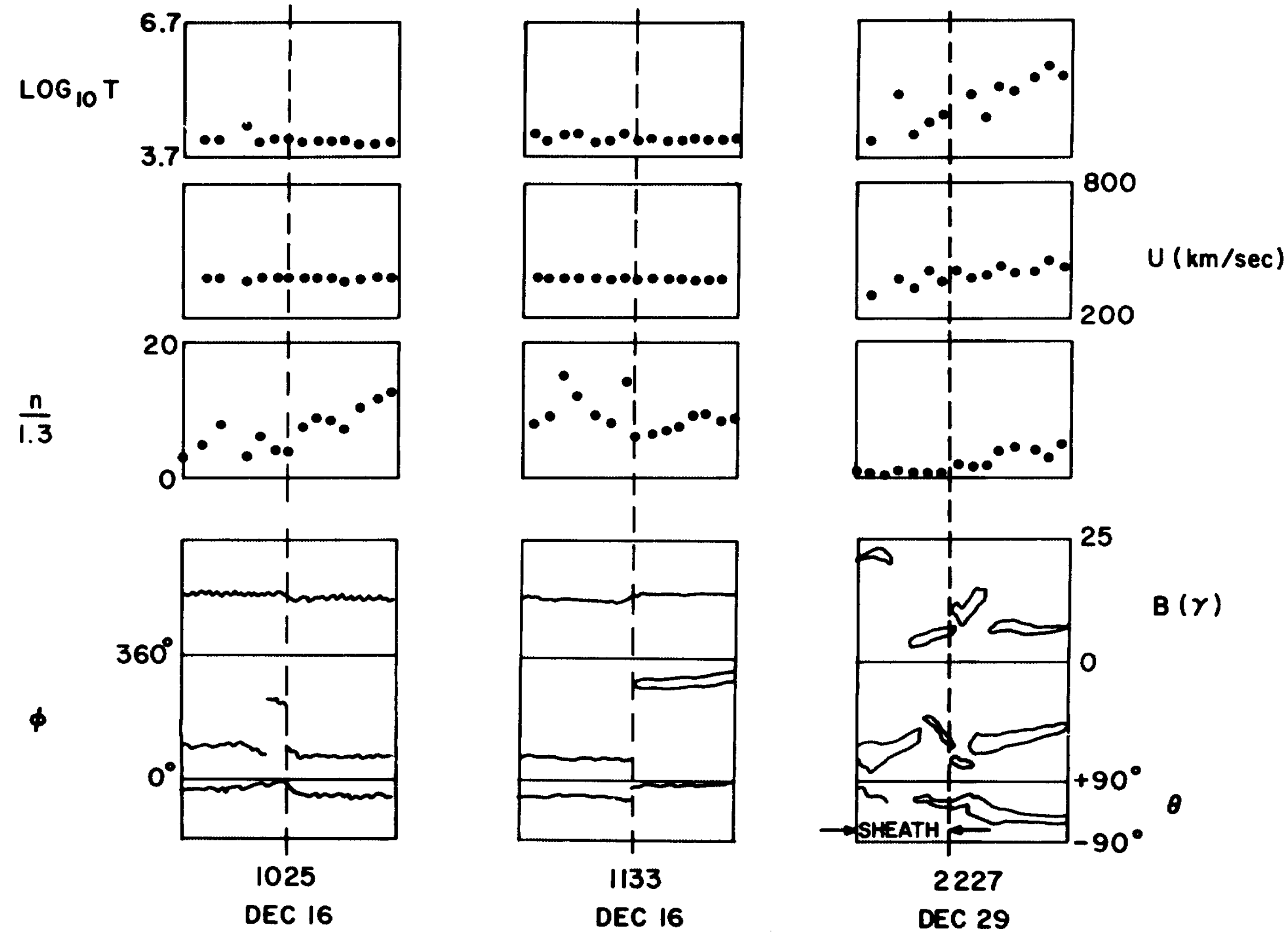

Figure 2d. Interplanetary plasma and magnetic field data for intervals near the times of 3 of the events in Table I. From top to bottom are the proton temperature, bulk speed and density, the magnetic field intensity, magnetic field longitude ϕ and latitude θ. These quantities are plotted versus time; the width of each box corresponds to 45 minutes. The plasma points are at 3 minute intervals. The magnetic field traces are from contiguous 20 sec. averages which are computed from averages of the measured magnetic field components.

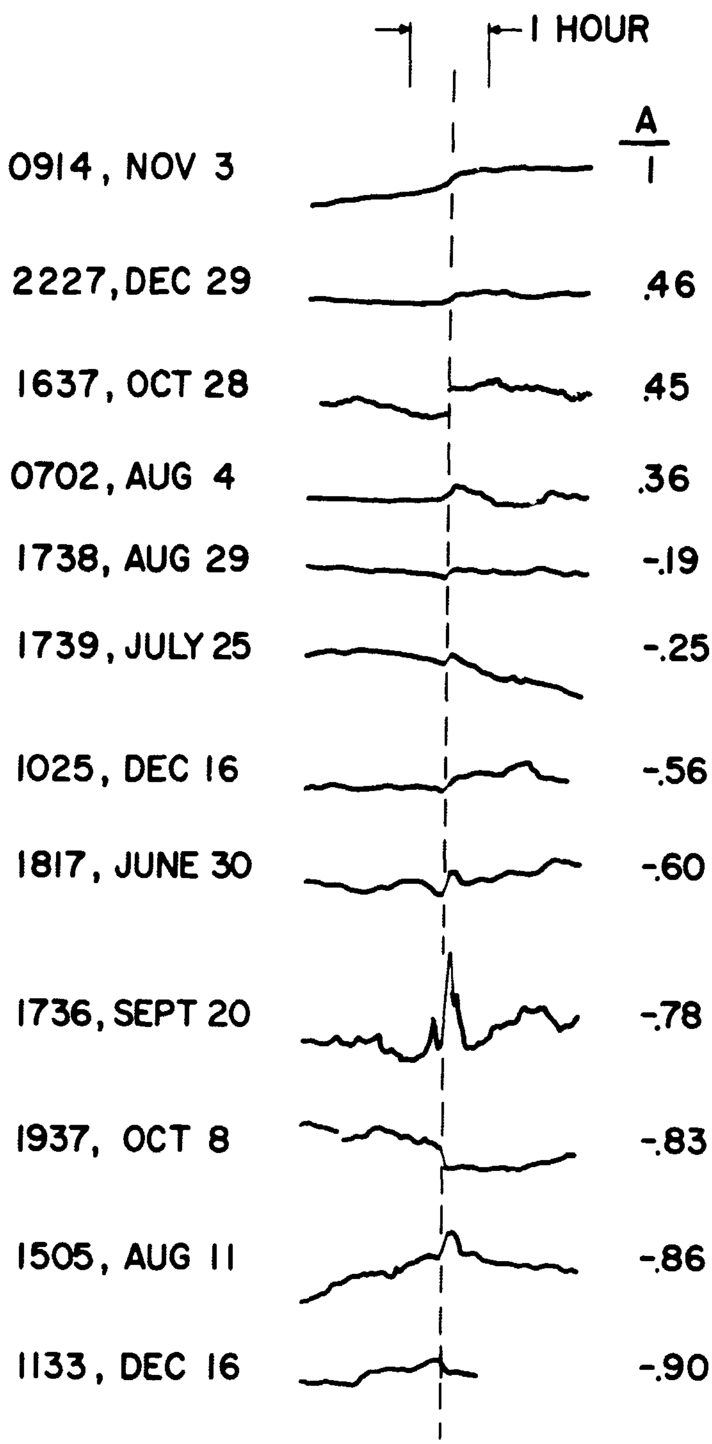

Figure 3. Magnetograms from San Juan showing the changes in the H component of the earth's magnetic field which were caused by the interplanetary structures shown in Figure 2. These are arranged in order of A. Note that ssc's (A near 1) are very distinctive, consisting of a rapid, step-like rise from one base value of H to another. The si's (A near −1), are quite different, but nevertheless distinctive; two are pulses, and two are negative steps. Intermediate A s correspond to less distinctive changes in H.

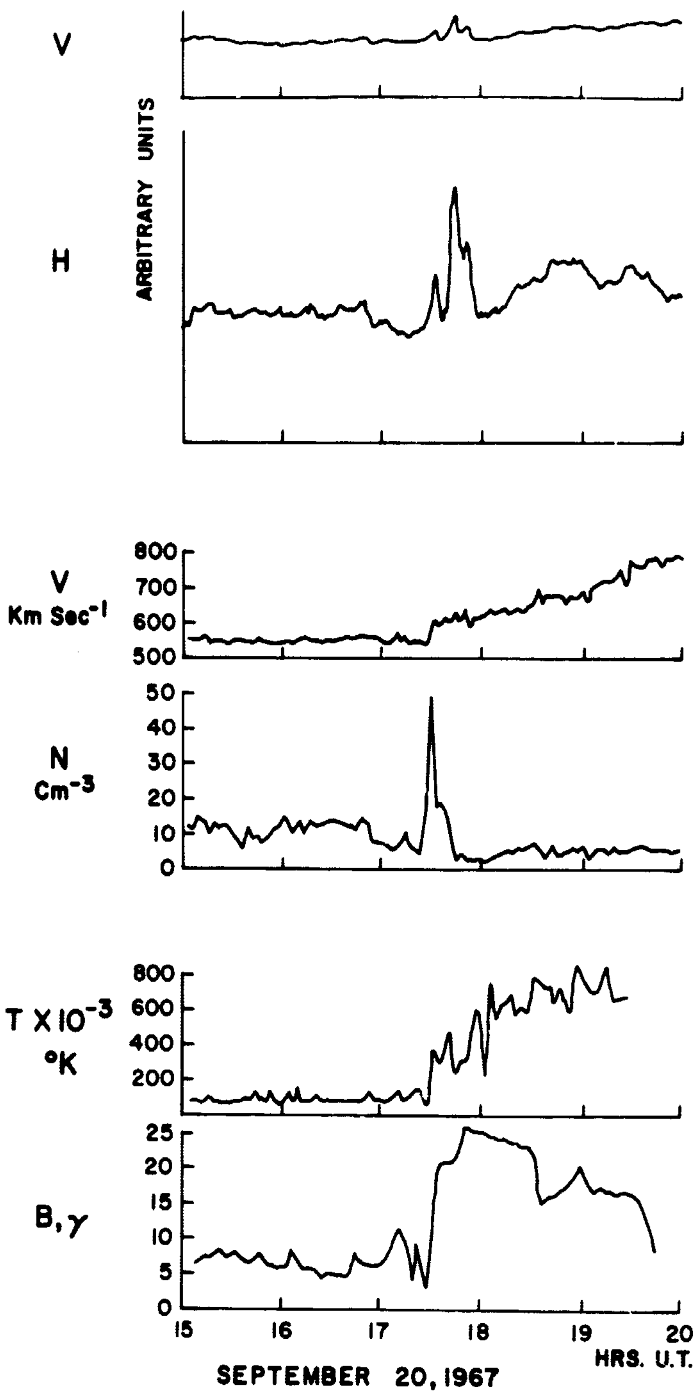

Figure 4. Data for the Sept. 20, 1967 event. The vertical and horizontal components of the earth's magnetic field are shown at the top. The event of interest is the multiple pulse between 1700 and 1800 UT. Also shown are the proton bulk speed, density and temperature together with the magnetic field intensity. Note that the magnetogram pulse is associated with a density pulse which is followed by a hot, high-speed plasma with a relatively large magnetic field energy density. The flow parameters suggest that the event was caused by a narrow, high-speed stream which piled up matter ahead of it which in turn was preceded by a hydromagnetic shock.

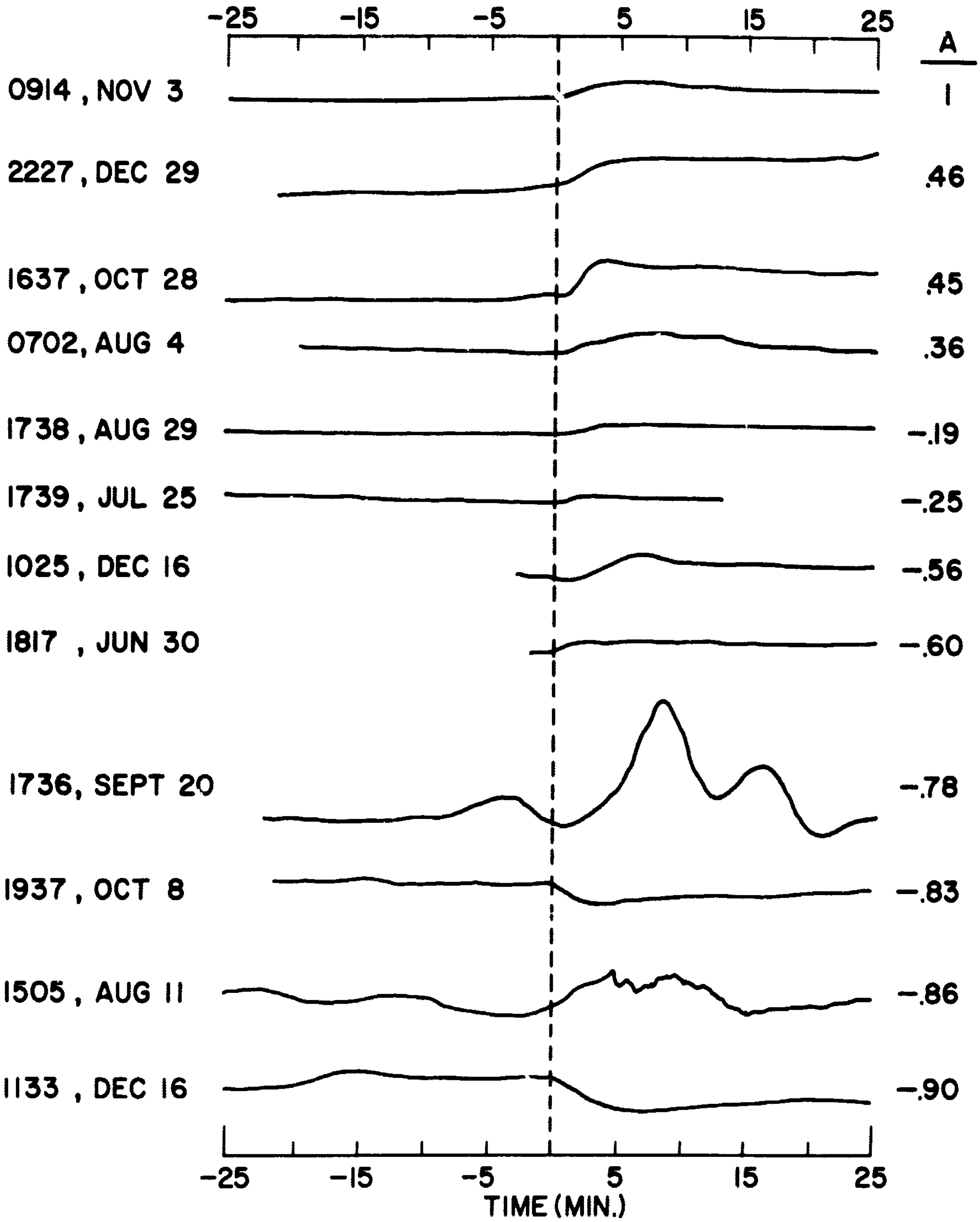

Figure 5. Rapid run magnetograms for the events in Figure 3.